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題目(和文)	ナノスケール材料の光学的および光物理的特性における表面プラズモンポラリトンの影響の研究
Title(English)	Study of the effect of surface plasmon polariton on optical and photophysical properties of nanoscale materials
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Thesis Outline

Thesis title: Study of the effect of surface plasmon polariton on optical and photophysical properties of nanoscale materials
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Supervisor: Prof. Martin VACHA

Outline:

This thesis has five chapters. The first chapter reviews the physics of surface plasmon polaritons. In this chapter, wave equations of surface plasmon polaritons are derived from Maxwell's equations. By combining the characteristics of surface plasmon polaritons and the wave equations, the wave vector of surface plasmon polaritons is obtained as a function of incident wavelength and dielectric constant of metal and dielectric materials. The important properties, including dispersion relationship between incidence and SPP, propagation length along interface and the decay length into metal and dielectric, are derived from the wave equations. The contents of this chapter provide the theoretical basis for the experiments discussed in the following chapters.

In this thesis, nanohole arrays fabricated on a gold film with a pitch of 500 nm, a diameter of 250 nm, and a depth of 40 nm are used as the SPP generating structure for all the three experiments. As mentioned in section 1.2, the performance and resonance wavelength can be intentionally designed by modifying the parameters of the metal nanohole arrays. Ideally, SPP resonance wavelength should be designed based on the properties of the target sample (e.g., emission spectrum, absorption spectrum) to maximize the interaction between SPP and the target material. However, in this thesis, the same SPP generating substrate is used for different types of nanomaterials. The reason is that the aim of this thesis is not to improve the interaction between SPP and target materials and thus improve device performance. The aim of this thesis is to understand the physics of how SPP will influence the optical or photophysical properties of nanomaterials. Therefore, keeping the structure consistent, thus keeping the properties of SPP consistent, makes it easier to understand the physics of the interaction between SPP generated on the substrate and the materials deposited on the substrate.

In chapter 2, CdSe/ZnS core-shell quantum dots (QDs) are deposited on the SPP generating substrate. The properties of SPP substrate are first simulated by finite-difference time-domain simulations. Both ensemble and single quantum dots are deposited on the substrate. The quantum dots are excited by either a 540 nm laser or a 450 nm laser, where the 540 nm laser can generate SPP on the substrate according to the dispersion relationship and the 450 nm laser can not. By comparing the emission intensity of quantum dots under 540 nm excitation and 450 nm excitation, we find that SPP can not only enhance the absorption but also the emission of QDs at both ensemble and single particle levels. The absorption enhancement is explained by the local field enhancement caused by SPP, and the emission enhancement originates from the interaction between surface plasmon polaritons and excitons generated in quantum dots. This experiment, for the first time, separates the absorption part and emission part of total emission enhancement of quantum dots caused by SPP and provides a deeper view into the interaction between SPPs and QDs.

In chapter 3, supramolecular nanofibers are deposited on the substrate with gold nanohole arrays. The nanofibers are fabricated by self-assembly of tris(phenylisoxazolyl)benzene derivative molecules, and their diameter ranges from nanometers to hundreds of nanometers. These nanofibers are shown to function as waveguides for fluorescence excited in one location by a focused 360 nm laser. We demonstrate that the waveguiding phenomenon is quite different between nanofibers deposited on flat gold and gold nanohole arrays. For nanofibers on the gold nanohole arrays, the guided light exhibit strong leakage. The spectrum of the leaked light is consistent with the SPP resonance wavelength, and its polarization corresponds to the TE waveguided mode.

In chapter 4, supramolecular nanofibers that do not support waveguiding modes are deposited on the SPP generating substrate, and how SPPs influence exciton diffusion in the nanofiber is explored. Specifically, the beam size of the 457 nm laser is calibrated to be as small as possible. The 457 nm laser is then used to excite the nanofibers. The size of excitation laser beam and the range of fluorescence of nanofibers are both recorded by a CCD camera. Results show that when nanofibers are deposited on a gold substrate, the range of fluorescence is larger than the size of excitation laser beam, demonstrating that exciton diffusion is happening in the nanofibers. The exciton diffusion length is calculated from the difference between the size of fluorescence and the laser beam. Results show that for nanofibers deposited on a glass substrate, there's no exciton diffusion observed. For nanofibers deposited on flat gold and gold nanohole arrays, exciton diffusion is observed. For nanofibers deposited on gold nanohole arrays, the diffusion length is influenced by the direction of nanofibers as compared to the direction of nanoholes. When the nanofiber is propagating in the same direction as nanoholes, the diffusion length is longer, demonstrating that SPP is enhancing the exciton diffusion in the nanofibers.

From quantum dots to supramolecular nanofibers, this thesis explores the influence of surface plasmon polaritons on the emission of quantum dots, waveguiding and exciton diffusion of supramolecular nanofibers. This thesis provides deeper insight into the interaction between surface plasmon polaritons and nanomaterials from both an optical and photophysical perspective.